Global Repeat Hydrographic/CO_2/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives: *Carbon Inventories And Fluxes*

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1.0 PROJECT SUMMARY

The Repeat Hydrography CO_2/tracer Program is a systematic and global re-occupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers and related parameters. It builds upon earlier programs (e.g., World Ocean Circulation Experiment (WOCE)/Joint Global Ocean Flux Survey (JGOFS) during the 1990s) that have provided full depth data sets against which to measure future changes, and have shown where atmospheric constituents are getting into the oceans. The Repeat Hydrography CO_2/tracer Program (Figure 1; Table 1) will reveal much about internal pathways and changing patterns that will impact the carbon sinks on decadal time scales.

The program is designed to assess changes in the ocean's biogeochemical cycle in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can also be followed through long-term measurements. Below the 2000m depth of the Argo array, Repeat Hydrography is the only global measurements program capable of observing these long-term trends in the ocean. The program will also provide data for the Argo sensor calibration (e.g., www.argo.ucsd.edu), and support for continuing model development that will lead to improved forecasting skill for oceans and global climate. By integrating the scientific needs of the carbon and hydrography/tracer communities, major synergies and cost savings have been achieved. The philosophy is that in addition to efficiency, a coordinated approach will produce scientific advances that exceed those of having individual carbon and hydrographic/tracer programs. These advances will contribute to the following overlapping scientific objectives: 1) data for model calibration and validation; 2) carbon inventory and transport estimates; 3) heat and freshwater storage and flux studies; 4) deep and shallow water mass and ventilation studies; and 5) calibration of autonomous sensors.

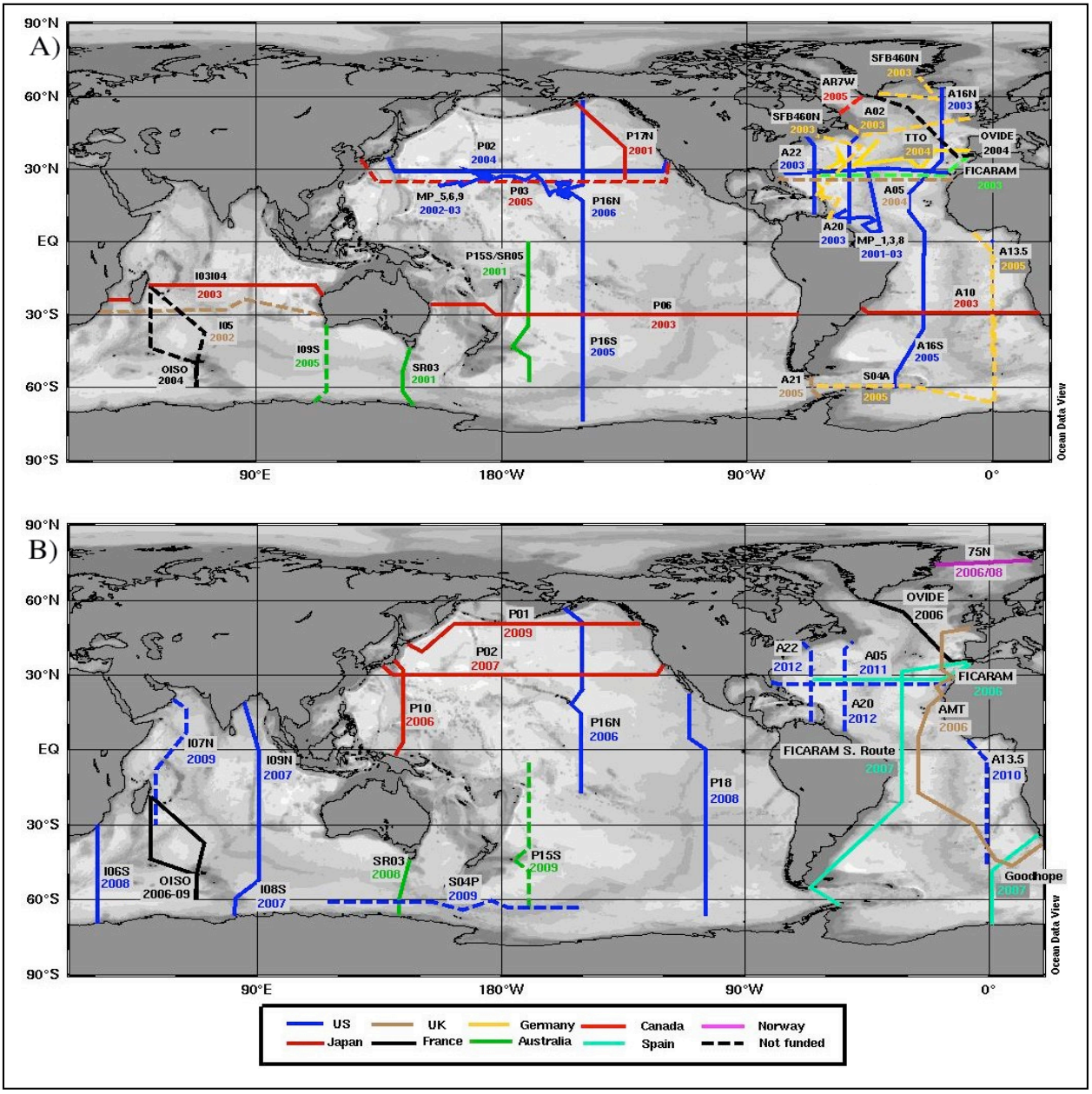

Figure 1. Global map of completed (A) and planned (B) Repeat Hydrography CO_2/tracer Program hydrographic sections with carbon system measurements. Solid lines indicate funded lines. Dashed lines indicate planned lines that are not fully funded at this time. The U.S. cruises are designated with blue lines. Solid lines are funded cruises.

Table 1. Sequence of Repeat Hydrography CO_2/tracer completed and planned cruises in the oceans - from 2003 to 2014.

Schedule of US CO2/CLIVAR Hydrography Lines (as of 8/31/07)						
Dates	**Cruise**	**Days**	**Ports**	**Year**	**Contact/Chief Scientist overall coordinator: Jim Swift, SIO**	**Ship**
06/19/03-7/10/2003	A16N, leg 1 Planning Cruise results	22	Reykjavik-Madeira	1	Bullister, PMEL	Ron Brown
07/15/03-8/11/2003	A16N, leg 2 Planning Cruise results	28	Madeira - Natal, Brazil	1	Bullister, PMEL	Ron Brown
09/15/03-10/13/2003	A20 Cruise results	29	WHOI - Port Of Spain	1	Toole, WHOI	Knorr
10/16/03-11/7/2003	A22 Cruise results	21	Port Of Spain - WHOI	1	Joyce, WHOI	Knorr
06/15/04-7/25/2004	P2, leg 1 Cruise results	41	Yokohama-Honolulu	2	Robbins, SIO	Melville
07/28/04-8/27/2004	P2, leg 2 Cruise results	32	Honolulu - San Diego	2	Swift, SIO	Melville
01/09/05-2/22/2005	P16S Cruise results	45	Wellington-Tahiti	3	Sloyan/Swift, WHOI/SIO	Revelle
01/11/05-2/26/2005	A16S Planning Cruise results	48	Punta Arenas - Fortaleza	3	Wanninkhof,Doney; NOAA/AOML,WHOI	Ron Brown
02/13/06-3/3/2006	P16N, leg 1 Planning	18	Tahiti-Honolulu	4	Sabine; NOAA/PMEL	Thompson Schedule
03/10/06-3/30/2006	P16N, leg 2 Planning	21	Honolulu-Kodiak	4	Feely; NOAA/PMEL	Thompson Schedule
02/04/07-3/17/2007	I8S	38	Dunedin, NZ-Perth	5	Swift, SIO	Revelle
03/22/07-5/2/2007	I9N	38	Perth-Colombo, Sri Lanka	5	Sprintall, SIO	Revelle
02/04/08-3/17/2008	I6S	43	Cape Town	6	Speer, FSU	Revelle
12/06/07-1/16/2008	P18, Leg 1	32	San Diego-Easter Island	6	Johnson, Bullister, PMEL	Ron Brown
01/19/08-2/23/2008	P18, Leg 2	35	Easter Island- Punta Arenas	6	Johnson, Bullister, PMEL	Ron Brown
austral summer early 2008	S4P/P16S Leg 1	25.5	Wellington-Perth	6		?

austral summer early 2008	S4P/P16S Leg 2	25.5	Wellington-Perth	6		?
2009	A13.5	40	Abidjan-Cape Town	7	future planning	NOAA
2009	I7N	47	Port Louis/Muscat		future planning	UNOLS
2010	A10	29	Rio de Janeiro-Cape Town	8	future planning	NOAA
2010	I5	43	Perth - Durban		future planning	UNOLS
2011	A5	30	Tenerife-Miami	9	future planning	NOAA
2011	A20/A22	29	Woods Hole-Port of Spain-Woods Hole		future planning	UNOLS
2012	A16N	29		10	future planning	NOAA
2012	P06				future planning	UNOLS
2013	A16S			11	future planning	NOAA
2013	P02				future planning	UNOLS
2014	P16N			12	future planning	NOAA
2014	P16S				future planning	UNOLS

The Repeat Hydrography CO_2/tracer Program is being implemented to maintain decadal time-scale sampling of ocean transports and inventories of climatically significant parameters in support of Objective 7 (Ocean Carbon Monitoring Network) of the Program Plan for Building a Sustained Observing Network for Climate. The sequence and timing for the sections (Figure 1) takes into consideration the program objectives, providing global coverage, and anticipated resources. Also considered is the timing of national and international programs, including the focus of CLIVAR in the Pacific in the 2005-2008 timeframe; the Ocean Carbon and Climate Change Program (OCCC) that emphasizes constraining the carbon uptake in the Northern Hemisphere oceans, in part, in support of the North American Carbon Program (NACP); and the international Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program. In addition, the proposed sections are selected so that there is roughly a decade between them and the WOCE/JGOFS occupations.

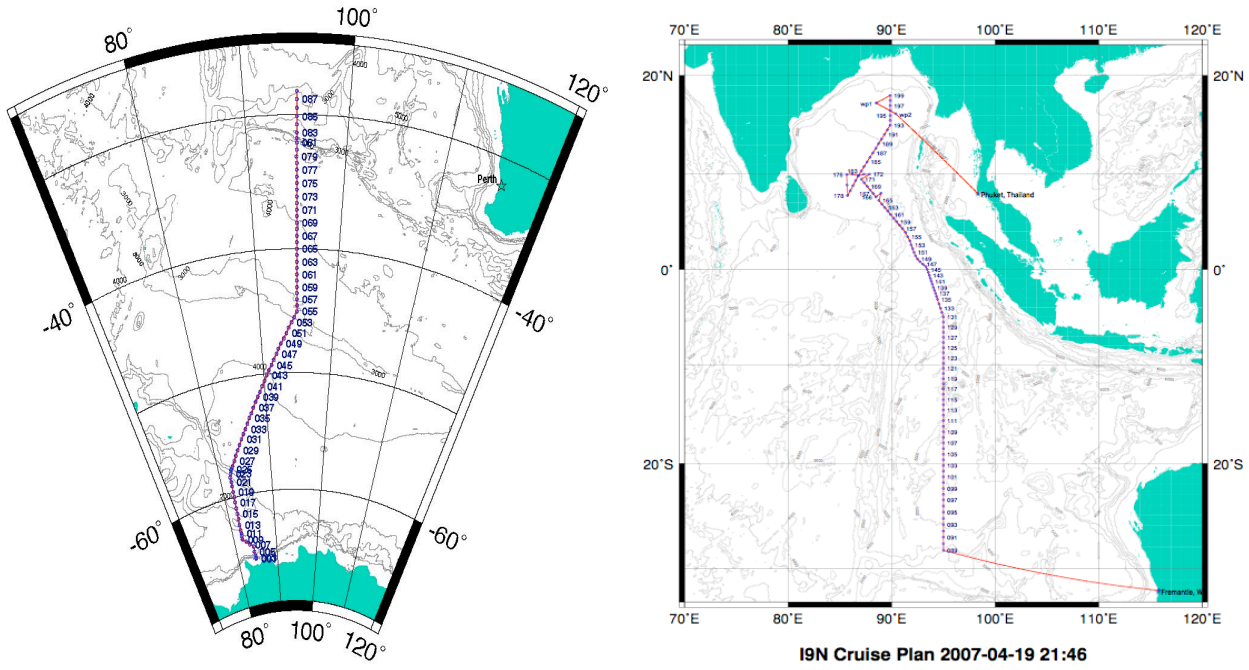

Figure 2. Cruise Tracks of Repeat Hydrography I8S and I9N during Feb – May 2007 in the Indian Ocean.

The scientific objectives are important both for the CLIVAR and the OCCC programs, and for operational activities such as Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). In mid-2001 the US scientific steering committees of CLIVAR (www.clivar.org) and the Carbon Cycle Science Program, (CCSP; www.carboncyclescience.gov) proposed the creation of a joint working group to make recommendations on a national program of observations to be integrated with international plans. Several community outreach efforts have been implemented to provide information about the program, such as a web site with interactive forum (http://ushydro.ucsd.edu/index.html), articles in EOS (Sabine and Hood, 2003) and the JGOFS newsletter, as well as AGU and Ocean Science meeting forums. The Repeat HydrographyCO_2/tracer Program addresses the need, as discussed by the First International Conference on Global Observations for Climate (St. Raphael, France; October 1999), that one component of a global observing system for the physical climate/CO_2 system should include periodic observations of hydrographic variables, CO_2 system parameters and other tracers throughout the water column (Smith and Koblinsky, 2000); (Fine et al., 2001). The large-scale observation component of the OCCC has also defined a need for systematic observations of the invasion of anthropogenic carbon in the ocean superimposed on a variable natural background (Doney et al., 2004). The CCSP has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system components. Through this plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the ocean's contribution to the state of the climate and on the state of the observing system. The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

Recognizing the need to develop an international framework for carbon research, various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the Intergovernmental Oceanographic Commission (IOC), and the Scientific Committee on Oceanic Research (SCOR) have worked together to develop research strategies for global carbon cycle studies. Based on the recommendations coming from these programs, NOAA and NSF have co-sponsored the Repeat Hydrography CO_2/tracers Program, with program direction coming from the Repeat Hydrography Oversight Committee (Richard Feely and Lynne Talley, co-chairs; http://ushydro.ucsd.edu/index.html). Many other nations are also sponsoring similar carbon studies that are comparable in focus and have been designed to be complimentary to our program (http://www.clivar.org/carbon_hydro/index.htm). Consequently, there is an immediate need for global-scale coordination of these carbon observations and research efforts to achieve the goal of a global synthesis. There is also an urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community. Because of these issues, the Global Carbon Project (GCP; http://www.globalcarbonproject.org/) has initiated the International Ocean Carbon Coordination Project (IOCCP; http://www.ioc.unesco.org/ioccp/) to: (1) gather information about on-going and planned ocean carbon research and observation activities, (2) identify gaps and duplications in ocean carbon observations, (3) produce recommendations that optimize resources for international ocean carbon research and the potential scientific benefits of a coordinated observation strategy, and (4) promote the integration of ocean carbon research with appropriate atmospheric and terrestrial carbon activities. It is through the workings of the IOCCP and international CLIVAR that international coordination of data management, data synthesis and scientific interpretation of the global repeat sections results will be implemented. In addition, the

Repeat Hydrography CO_2/tracer Program is being managed in accordance with the COSP Ten Climate Monitoring Principals.

2.0 FY 2007 PROGRESS REPORT AND ACCOMPLISHMENTS

2.1.1 I8S Cruise Results

A hydrographic survey consisting of LADCP/CTD/rosette sections, bio-optical casts, trace metals rosette sections, underway shipboard ADCP, float deployments in the southern Indian Ocean was carried out in February and March 2007. The R/V Revelle departed Dunedin, New Zealand on 4 February 2007. A total of 88 stations were occupied. Eighty-eight LADCP/CTD/Rosette casts, 39 Trace metals Rosette casts, 25 bio-optical casts were made, and 14 ARGO floats were deployed from 15 February to 14 March. Water samples (up to 36) and CTD data were collected on each LADCP/CTD/rosette coast in most cases to within 10-20 meters of the bottom. Salinity, dissolved oxygen and nutrient samples were analyzed for up to 36 water samples from each cast of the principal LADCP/CTD/Rosette program. Water samples were also measured for Total DIC, Total Alkalinity, CCs and CDOM, and samples were collected for DOC, POC, Helium/Tritium, and C13. Underway surface pCO_2, temperature, conductivity, dissolved oxygen, fluorometer, meteorological and multi-beam acoustical bathymetric measurements were made. The cruise ended in Fremantle, Australia on 17 March 2007.

2.1.2 I9N Cruise Results

The R/V Roger Revelle completed a hydrographic survey of CLIVAR/CO_2 section I9N in the Indian Ocean, nominally along 95°E (between 28°S and 4°S) and up into the Bay of Bengal, from 22 March to 01 May 2007. The 41 day cruise began at 0800 22 March 2007 from Fremantle, Western Australia and ended at 0800 01 Mary 2007 in Phuket Thailand.

A total of 111 stations were occupied. The station numbers were consecutive with those from the I8S cruise (Chief Scientist Jim Swift) that was occupied just prior to I9N from 2 February to 17 March 2007. The first cast of I9N, Station 89, was a reoccupation of the I8S Station 88. Station spacing was nominally 30 nm apart, except at the equator where station spacing was 20 nm. Stations 89 through 147 are exact repeats of the 1995 WOCE I9N Stations 155 to 212. Our transect then deviated slightly westwards from WOCE I9N to avoid the Indonesian EEZ, before angling northwestward up into the Bay of Bengal. Stations 172 through 176 are reoccupations of 1995 WOCE I1E Stations 991, 990, 989 (also WOCE I9N Station 268), 987, and 986. Stations 178 through 193 followed the original WOCE I9N section Station 260 to 271 across the north-eastward central axis of the Bay of Bengal. Station 182 repeated station 174 as well as the corresponding WOCE I1 (989) and WOCE I9N (268) stations. After a short northward section from Station 193, our station sampling ended at Station 199 in ~2000 m water depth.

Each station consisted of a CTD/LADCP/rosette cast to within 10-15 m of the bottom. Water samples (usually 36 bottles) at each station were analyzed for salinity, nutrients, dissolved oxygen, dissolved inorganic carbon, total alkalinity, dissolved organic matter, colored dissolved organic matter, chlorofluorocarbons, helium/tritium, particulate organic carbon, carbon-14, bacteria and chlorophyll. Trace metal casts to 1000 m were conducted at approximately every other station for a total of 49 trace metal casts. The trace metal casts were conducted near the same locations as the CTD profiles and were either before or after the full-depth casts depending on time of day. Optical profiles were collected once each day when on station, generally near 12:00 – 14:00 local time. Argo floats were deployed at 14 locations upon departure from a

station. Underway surface pCO_2, temperature, conductivity, dissolved oxygen, fluorometer, meteorological, aerosol and multi-beam acoustical bathymetric measurements were also made along the cruise track. No major problems were encountered on the cruise and all major cruise objectives were achieved.

2.2 CTD/O_2 and Bottle Salinity (Baringer, Johnson, and Langdon)

While analyses of repeat hydrographic data are not funded through this proposal, they are vital to the use of these data, and our efforts in this regard in FY2007 are summarized here. Our analysis of subpolar mode water variability using the 2003 A16N data (Johnson and Gruber, 2007) was published. Our submitted analyses of repeat hydrographic section data also demonstrated significant AABW warming in the western basins of the S. Atlantic Ocean (Meredith et al., 2007) and the main deep basins of the Pacific Ocean (Johnson et al., 2007). Analysis of bottom water variability in the eastern Indian Ocean by comparing the 2007 repeat of I8S/19N to the 1994-1995 section data along the same track is in progress. While there is no apparent warming north of the Southeast Indian Ridge crossed at about 45 °S by this section, there is a warming of roughly 0.1 °C below about 3500 m, again in the Antarctic Bottom Water (AABW; Fig. 3). Together, the results in the S. Atlantic, the Pacific, and the S. Indian Oceans suggest the possibility of a global pattern of AABW warming in the past decade, which could constitute an important mode of climate variability, and a significant contribution to the global heat budget. Finally, given the potential importance of global AABW variations mentioned above, we have worked to quantify its relative volume compared with North Atlantic Deep Water (Johnson, 2007).

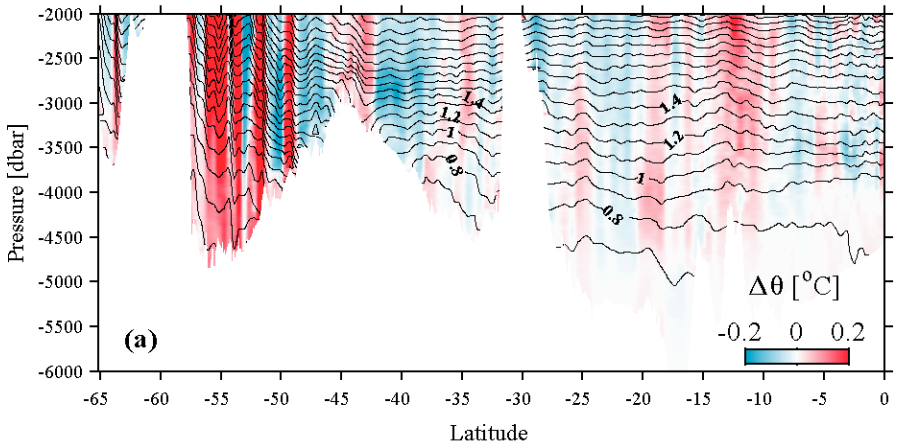

Figure 3. Difference of deep potential temperature, Δθ [°C], along WOCE Section I08S/I09N in the eastern Indian Ocean resulting from subtracting the 1994/5 data from the 2007 data. Red areas indicate warming and blue areas cooling with color saturation at ±0.2°C. Mean potential temperatures from all the data (black lines) are contoured at 0.1 °C intervals.

In FY 2007 the PMEL CTD group supported the coastal carbon survey cruise from Newport, Oregon to San Diego, California on the R/V Wecoma. We assembled the necessary CTD/O_2 equipment and arranged for pre- and post-cruise calibrations of all CTD/O_2 sensors. We purchased required supplies and equipment and shipped it to Newport and back from San Diego for the cruise. Our lead CTD/O_2 data processor participated on the cruise. We have now completed the final calibration of the cruise CTD/O_2 data.

During FY2007 the PMEL CTD group also began preparations for the FY2008 reoccupation of WOCE section P18. This repeat hydrography cruise will consist of a 42- and a 36-day leg, the former from San Diego to Easter Island, and the later from Easter Island to Punta Arenas. We have already bought long lead-time items like standard seawater and worked on building and readying equipment like frames and Niskin bottles. Dr. Johnson will serve as chief scientist for the second leg of P18 and has been involved in the planning.

2.3 Total Dissolved Inorganic Carbon (DIC) (Feely, Sabine and Wanninkhof)

I8S

Samples for DIC measurements were drawn according to procedures outlined in the Handbook of Methods for CO_2 analysis (DOE, 1994) from 10.4-L Niskin bottles (except Niskin 34, 9.6L) into cleaned 300-mL glass bottles. Over 2500 samples were analyzed for discrete DIC; full profiles were completed on odd numbered stations, with replicate samples taken from the surface, oxygen minimum, salinity maximum, and bottom Niskin-type bottles. On the even numbered stations, samples were drawn throughout the water column with focus on the upper 1000 m. The replicate samples were interspersed throughout the station analysis for quality assurance of the integrity of the coulometer cell solutions. No systematic differences between the replicates were observed.

I9N

Samples for DIC measurements were collected at every degree from 36 depths with three replicate samples. Some samples were also collected at every half-degree. The replicate seawater samples were taken from the surface, 1000 m, and bottom Niskin bottles and run at different times during the cell. No systematic difference between the replicates was observed. A total of 2526 samples for DIC were collected and analyzed during the cruise. The coulometers were calibrated by injecting aliquots of pure CO_2 (99.995%) by means of an 8-port valve outfitted with two sample loops with known gas volumes bracketing the amount of CO_2 extracted from the water samples for the two PMEL systems.

The stability of each coulometer cell solution was confirmed three different ways: the Certified Reference Material (CRM), Batch 78, supplied by Dr. A. Dickson of SIO, was measured at the beginning, gas loops in the beginning and at the end, and the duplicate samples at the beginning, middle, and end of each cell solution. The coulometer cell solution was replaced after 25 mg of carbon was titrated, typically after 9-12 hours of continuous use.

Calculation of the amount of CO_2 injected was according to the CO_2 handbook (DOE, 1994). The concentration of CO_2 ($[CO_2]$) in the samples was determined according to:

$$[CO_2] = Cal.factor * \frac{(Counts - Blank * Run\ Time) * K\ \mu mol/count}{Pipette\ volume * density\ of\ sample}$$

where Cal. Factor is the calibration factor, Counts is the instrument reading at the end of the analysis, Blank is the counts/minute determined from blank runs performed at least once for each cell solution, Run Time is the length of coulometric titration (in minutes), and K is the conversion factor from counts to µmol.

The instrument has a salinity sensor, but all DIC values were recalculated to a molar weight (µmol/kg) using density obtained from the CTD's salinity sensor. The results underwent initial quality control on the ship using property plots: DIC-depth, DIC-potential temperature, DIC-salinity and DIC-LAT-depth contour plots were used to analyze the quality of the data (Figure 4). The difference plot indicates DIC anomalies ranging from 5-55 µmol/kg in the upper

1000 m of the water column. These anomalies are due to uptake of anthropogenic CO_2, changes in mixing and ventilation of the water masses, and changes in biogeochemical processes. Our synthesis project will determine the relative contributions of each process to the total change in DIC over the 12-year interval.

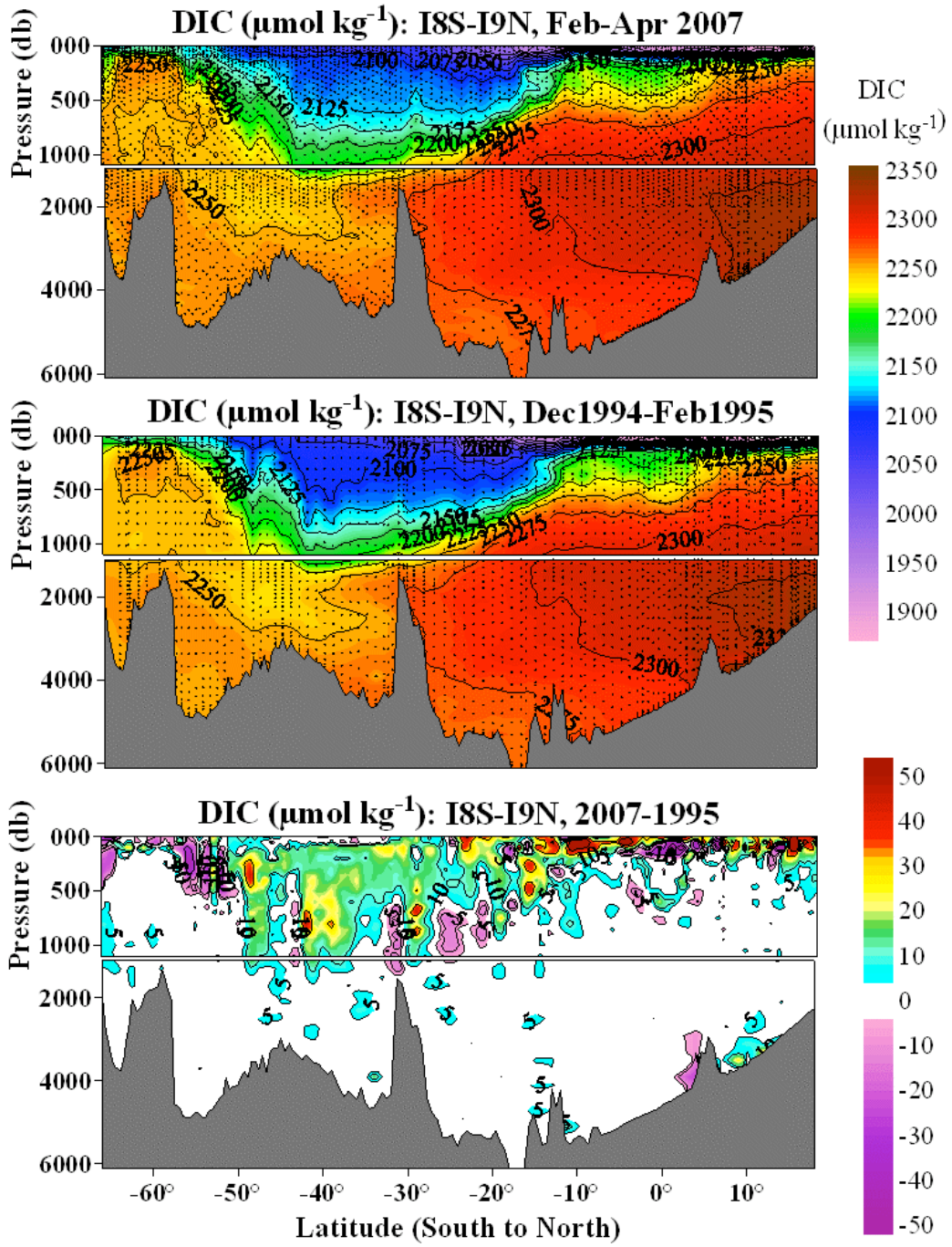

Figure 4. DIC in µmol kg^{-1} along the I8S and I9N section in the Indian Ocean along 95 °E. The gridded difference plot is shown on the bottom panel. The increases in DIC are the result of a combination of processes including anthropogenic CO_2 invasion and changes in circulation and biogeochemistry.

2.4 Discrete pCO_2 (Wanninkhof)

Underway pCO_2 measurements for I8 S and I9 N

Underway pCO_2 measurements were made on the R/V *Revelle* along the entire cruise track from Dunelin, New Zealand (46 ˚S, 170 ˚E) to the Northern end of the Bay of Bengal (17 ˚N, 90 ˚W). A total of 14942 surface water samples and 5600 air samples were taken. Sampling and data reduction followed standard protocol as outlined in (Pierrot et al., 2007). No major problems were encountered except that the water intake of the R/V *Revelle* occasionally breached the surface entraining bubbles and affecting the surface temperature measurements from the thermosalinograph. This occurred primarily during maneuvering while on station and is the cause of the spikes in the values shown in Figure 5.

The transit from New Zealand to the start of the hydrographic section at 83 ˚E, 64 ˚S went along 64 ˚S from 135 ˚E to 83 ˚E, providing a unique dataset near the ice edge of the Southern Ocean. The partial pressure difference of CO_2 between water and air (ΔpCO_2) as compared to the climatological values for March (Takahashi et al., 2007) is shown in Figure 6. The observations show a very strong CO_2 sink ranging from -40 to -120 μatm along 64 ˚S. The lowest values correspond to elevated chlorophyll values as determined from the shipboard fluorometer indicating that this sink is in response to strong biological activity. The observed sink is much greater than shown in the climatology, clearly indicating the value of these measurements to improve our understanding of the air-sea CO_2 fluxes in this data sparse region.

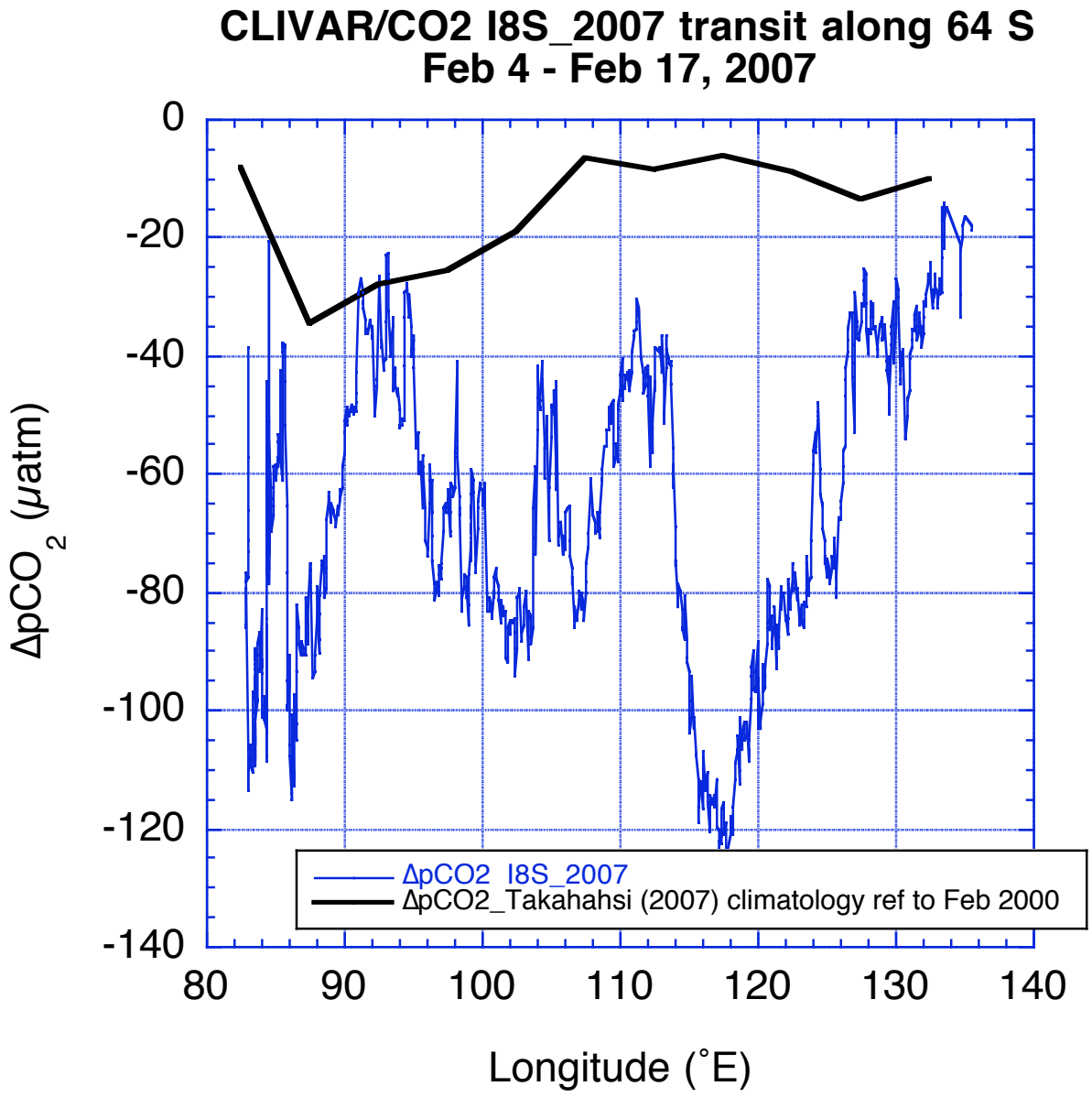

Figure 5. The ΔpCO_2 along zonal transect of 64 ˚S from February 4, 2007 to February 17, 2007 (thin line) compared to the climatology of Takahashi et al. (2007) (thick line) referenced to February 2000. The monthly climatological values are for a 4 by 5 ˚ grids centered on 64 ˚S.

The ΔpCO_2 observations along the hydrographic transect from 64 ˚S to 16 ˚N that occupied stations between 83 ˚E and 95 ˚E are shown in Figure 6. Going northward the ocean alternates from sink to source of CO_2 often delineated by gyre boundaries. The region turns from a sink in the polar region at 60 ˚S to a source in the sub-polar area at 50 ˚S and becomes a sink again at the boundary of the sub-polar and sub-tropical gyres around 40 ˚S. The subtropical gyre in the Austral summer is a weak source. There is a weak sink in the southern tropics. From 10 ˚S northward the region is a source of CO_2. Overall the pattern follows the climatology but measured ΔpCO_2 values on this cruise are slightly higher. The higher values from 55 ˚S to 40 S are in accord with the output of models as presented in Lovenduski et al., (2007) and Le Quere et al., (2007) that suggest that this is caused by increased upwelling of water with high CO_2 content in response to increasing westerly winds. The higher values observed in the north are associated

with higher salinities in the northern Bay of Bengal during the cruise compared to the cruises used in the climatology which are primarily those of the 1995 WOCE cruises in the Indian Ocean (Sabine et al., 2000).

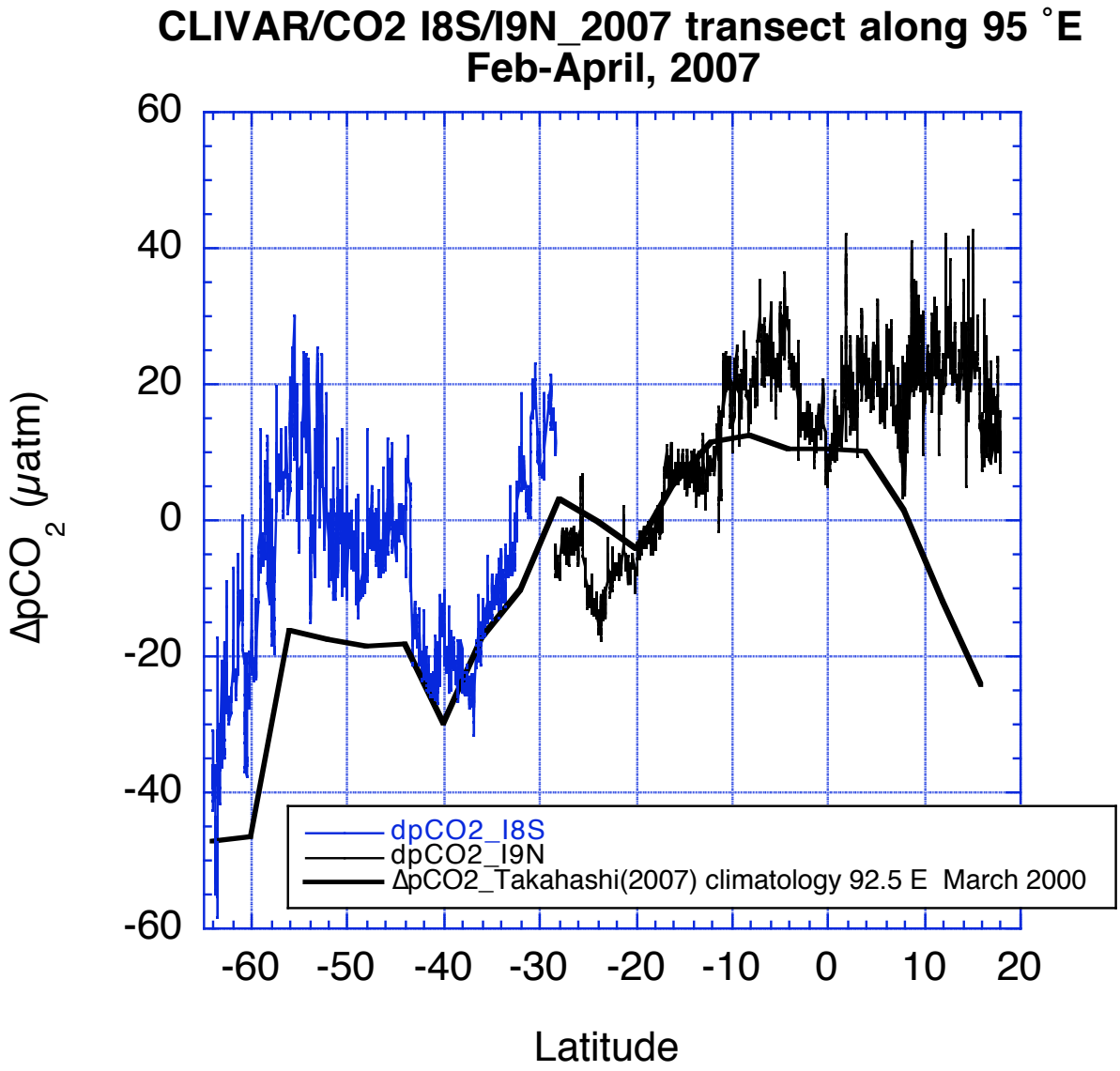

Figure 6. The ΔpCO2 along a quasi-meridional transect from 64 ˚S to 16 ˚N along a northward route between 82 and 95 ˚E from February to April 2007 (thin line) compared to the climatology of Takahashi et al. (2007) (thick line) referenced to March 2000. The monthly climatological values are on 4 by 5 ˚ grids centered on 92.5 ˚E.

2.5 Nutrients (Zhang)

In FY 2007 we developed Labview-based software for the auto-analyzer and made preparations for the P18 cruise which is scheduled for late 2007.

1. Software development for autoanalyzer: To obtain high quality nutrient data we need a data acquisition software that can correct for refractive index and background nutrients in low nutrient seawater that is routinely used as a matrix in preparing standard and used as wash solution in

seawater analysis using an autoanalyzer. We cannot use commercial autoanlyzer software which is designed for freshwater analysis and the correction for seawater is not available. Currently we are using a half-constructed and problematic "twinpeak" software that was constructed by several programmers over years but none of them had time or resources to finish it. Dr. Natchanon Amornthammarong has examined the current version of software and made significant modifications. We have added a user-friendly data reduction routine. We have also selected two suitable autosamplers, "Westco Scientific CS9000" and "CETAC ASX 520HS". These samplers can supply a large sample volume (25-50 ml) for simultaneous analysis of five nutrient constituents (nitrate, nitrite, ammonium, phosphate and silicate). Computer programs have been written to interface both autosamplers. A fully developed software will be shared with the PMEL nutrient group and other nutrient labs participating the Repeat Hydrography program. This is a key step toward a unified instrumentation for shipboard nutrient analysis in long-term ocean observation program.

2. We have participated in the international inter-comparison for nutrient in seawater organized by Dr. Aoyama of the Japanese Meteorological Research Institute who is also responsible for nutrient measurements in the Repeat Hydrography Program sponsored by the Japanese government. A total of 55 laboratories from 15 counties have participated in this exercise, including our Repeat Hydrography Program partner, the nutrient lab at Scripps Institution of Oceanography. Our measurements have provided high quality data to the inter-comparison as evidenced by high precision and the degree of agreement to the consensus values.

3. Preparation for P18 cruises: We have prepared chemical reagents, standard solutions and instruments for the P18 cruises. We have compared our nutrient standards with our previous standards and with standards from the Japanese Meteorological Research Institute.

2.6 Discrete Oxygen (Baringer and Langdon)

This year, support was provided for the maintenance of the existing photometric O_2 titration equipment, completion of the building of four new amperometric titration systems (three built last FY, one to be completed this FY), and training for all technicians on the use of the new systems. AOML/CIMAS will further prepare for P18 cruises including the pre-purchase of chemical reagents for the cruise. The group will also participate in the at-sea collection of discrete O_2 by contributing one technician working a twelve-hour daily shift on the east and west coast CO_2 surveys, including initial data reduction, and purchasing of all chemical reagents and supplies.

For the two cruises conducted in FY2007, samples were drawn from Niskin bottles into calibrated 140 ml iodine titration flasks using Tygon tubing with a Silicone adapted that fit over the petcock to avoid contamination of DOM samples. Bottles were rinsed twice and filled from the bottom, overflowing three volumes while taking care not to entrain any bubbles. The draw temperature was taken using a digital thermometer with a flexible thermistor probe that was inserted into the flask while the sample was being drawn. These temperatures were used to calculate mmol kg^{-1} concentrations, and a diagnostic check of bottle integrity. One-ml of $MnCl_2$ and one-ml of NaOH/NaI were added using a Repipetor, and the flask was stoppered and shaken. DIW was added to the neck of each flask to create a water seal. The flasks were stored in the lab in plastic totes at room temperature for 1-2 hours before analysis.

On the West Coast CO_2 cruise, dissolved oxygen analyses were performed with a MBARI-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365 nm wavelength ultra-violet light. The titration of the samples and the data

logging were controlled by a 386 PC running the Oxygen program written by Gernot Friedrich. Thiosulfate was dispensed by a Dosimat 665 fitted with a 5.0 ml buret. The whole-bottle titration technique of Carpenter (1965a) with modifications by Culberson et al. (1991) was used, but with a more dilute solution of thiosulfate (10 g L^{-1}). Standard curves were run each day. The reagent blank was taken to be the intercept of the standard curve and compared to the reagent blank determined by the convention two-titration method. The autotitrator and Dosimat generally performed well. Endpoints were noted to be noisy during periods of particularly bad weather. Thiosulfate molarities were calculated from titration of the standard iodate solution dispensed using a calibrated Wheaton bottle top dispensor and corrected to 20ºC. The 20ºC molarities were plotted versus time and were reviewed for possible problems. Blank volumes and thiosulfate molarities were smoothed (linear fits) at the end of the cruise and the oxygen values recalculate. Oxygen flask volumes were determined gravimetrically with degassed deionized water to determine flask volumes at AOML and corrected for the buoyancy factor. The Dosimat and Wheaton positive displacement dispenser used for dispensing the KIO_3 were calibrated in the same way. Liquid potassium iodate standard solution with a normality of 0.0100 was prepared and bottled at AOML prior to the cruise. A single batch was used during the cruise.

On the Gulf of Mexico East Coast Carbon Cruise (GOMECC, see AOML Hydrography Group Type) twenty-four dissolved oxygen samples plus two duplicates were drawn from each station except the shallow costal stations where fewer samples were drawn depending on the depth. Total number of samples collected was 1247. A total of 133 sets of duplicates were run. The difference between replicates averaged 1.3 umol kg^{-1} for stations 1-45. The mixing time between additions by the titrator was increased from 4 to 8 s. This improved the reproducibility significantly. The difference between replicates for stations 46-90 averaged 0.4 umol kg^{-1}. The total number of samples flagged after initial shipboard reduction of quality control: Questionable (QC=34): Not reported (QC=1).

Additional oxygen samples were drawn from the ship's uncontaminated seawater line for comparison for the purpose of checking the calibration of the UNH Aanderra Optode oxygen sensor and for comparison with the oxygen sensor on the UGA CO_2 buoy.

Dissolved oxygen analyses were performed with an automated oxygen titrator using amperometric end-point detection (Culberson and Huang, 1987). This was the first full cruise performed by AOML using this system. The titration of the samples and the data logging and graphical display was performed on a PC running a program written by Ulises Rivero of AOML. The titrations were preformed in a climate controlled lab at 18.5°C - 20°C. Thiosulfate was dispensed by a 2 ml Gilmont syringe driven with a stepper motor controlled by the titrator. Tests in the lab were performed to confirm that the precision and accuracy of the volume dispensed were comparable or superior to the Dosimat 665. The whole-bottle titration technique of (Carpenter, 1965b) with modifications by (Culberson and Knapp, 1991) was used. Four replicate 10 ml iodate standards were run every 24 hours. The reagent blank determined as the difference between V1 and V2, the volumes of thiosulfate required to titrate 1 ml aliquots of the iodate standard, was determined at the beginning and end of the cruise. This method was found during pre-cruise testing to produce a more reproducible blank value than the value determined as the intercept of a standard curve. The temperature corrected molarity of the thiosulfate titrant was determined as given in (Dickson, 1994).

2.7 Chlorofluorocarbons (Bullister)

Samples for the analysis of dissolved CFC-11 and CFC-12 were drawn from ~ 4100 of the water samples collected during the I8S/I9N expedition. As a pilot study, the PMEL CFC analytical system was modified for the I8S/I9N expedition to allow analysis of ultra-trace levels of sulfur hexafluoride (SF_6) along with CFCs from the same water sample. Efforts were made to sample CFCs and SF_6 (CFCs/SF_6) from the same bottles sampled for carbon parameters (DIC, alkalinity, pCO_2 and pH) and other tracers. Specially designed water sampling bottles were used on the cruise to minimize CFC/SF_6 contamination. When taken, water samples for CFCs/SF_6 analysis were the first samples drawn from the sample bottles. Care was taken to coordinate the sampling of CFCs/SF_6 with other samples to minimize the time between the initial opening of each bottle and the completion of sample drawing. In most cases, CFCs/SF_6, helium-3, dissolved oxygen, DIC, alkalinity and pH samples were collected within several minutes of the initial opening of each bottle. To minimize contact with air, the CFCs/SF_6 samples were drawn directly through the stopcocks of the 12-liter bottles into 250 cc precision glass syringes. The syringes were immersed in a holding bath of fresh water until analyzed.

For air sampling, a ~100 meter length of 3/8" OD Dekaron tubing was run from the laboratory to the bow of the ship.

Concentrations of CFC-11, CFC-12 and SF_6 in air samples, seawater and gas standards were measured by shipboard electron capture gas chromatography (EC-GC) using techniques modified from those described by (Bullister and Weiss, 1988) and (Bullister and Wisegarver, 2007). For seawater analyses, an aliquot of ~ 200 cc of seawater was transferred from a 250 cc glass syringe to a large volume glass sparging chamber. The dissolved gases in the seawater sample were extracted by passing a supply of CFCs/SF_6-free purge gas through the sparging chamber and were concentrated on a cold-trap. The trap was then heated and its contents injected onto series of pre-columns and into the main analytical columns. The analytical system was calibrated frequently using a standard gas of known CFCs/SF_6 composition. Multiple injections of these loop volumes could be made to allow the system to be calibrated over a relatively wide range of concentrations. Air samples and system blanks (injections of loops of CFCs/SF_6-free gas) were injected and analyzed in a similar manner. The typical analysis time for seawater, air, standard or blank samples was ~12 minutes.

Concentrations of the CFCs in air, seawater samples and gas standards are reported relative to the SIO98 calibration scale (Prinn et al., 2000). Concentrations of the SF_6 in air, seawater samples and gas standards are reported relative to the NOAA-GMD calibration scale (Bullister et al., 2006). Concentrations in air and standard gas are reported in units of mole fraction CFC/SF_6 in dry gas, and are typically in the parts per trillion (ppt) range. Dissolved CFC concentrations are given in units of picomoles per kilogram seawater (pmol kg^{-1}). Dissolved SF_6 concentrations are given in units of femtomoles per kilogram seawater (fmol kg^{-1}). CFC/SF_6 concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a working standard. The response of the detector to the range of moles of CFC-12, CFC-11 and SF_6 passing through the detector remained relatively constant during the cruise. Full-range calibration curves were run at intervals of 10 days during the cruise. These were supplemented with occasional injections of multiple aliquots of the standard gas at more frequent time intervals. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of ~90 minutes) to monitor short-term changes in detector sensitivity. The precisions of measurements of the standard gas in the fixed volume (n=395) were ± 0.44% for CFC-12, 0.56% for CFC-11 and 1.2% for SF_6.

The efficiency of the purging process was evaluated periodically by re-stripping high concentration surface water samples and comparing the residual concentrations to initial values. These re-strip values were <1 % for all 3 compounds.

The average atmospheric concentrations determined during the cruise (based on sets of 5 air analyses made daily, n=23) were 252.9 +/- 4.4 parts per trillion (ppt) for CFC-11, 547.2 +/- 5.0 ppt for CFC-12 and 6.1 ppt =/- 0.1 for SF_6.

The estimated precisions for the CFC-11 and CFC-12 seawater analyses are shown in the following tables.

Table 2. Summary of number of CFC-11 samples taken and the estimated precision for the I8SI9N cruise

	CFC-11
Number of samples	4118
Number of replicates	293
Average standard deviation)	0.003 pmol kg^{-1} (or 1.0%), whichever is greater

Table 3. Summary of number of CFC-12 samples taken and the estimated precision for the I8SI9N cruise

	CFC-12
Number of samples	4118
Number of replicates	297
Average standard deviation)	0.003 pmol kg^{-1} (or 1%), whichever is greater

Table 4. Summary of number of SF6 samples taken and the estimated precision for the I8SI9N cruise

	SF6
Number of samples	4118
Number of replicates	234
Average standard deviation)	0.02 fmol kg^{-1} (or 2.0%), whichever is greater

A small number of water samples had anomalously high CFC/SF_6 concentrations relative to adjacent samples. These samples occurred sporadically during the cruise and were not clearly associated with other features in the water column (e.g. anomalous dissolved oxygen, salinity or temperature features). This suggests that these samples were probably contaminated with CFCs and/or SF_6 during the sampling or analysis processes. Measured concentrations for these anomalous samples are included in the preliminary data, but are given a quality flag value of either 3 (questionable measurement) or 4 (bad measurement). A quality flag of 5 was assigned to

samples that were drawn from the rosette but never analyzed due to a variety of reasons (e.g. power outage during analysis).

A section of CFC-12 concentrations along I8S/I9N in 2007 is shown in Figure 7. The strong latitudinal gradient in surface concentrations primarily reflects the latitudinal gradient in surface temperature, since the solubility of CFCs is greater at cold temperatures. CFC-12 concentrations in general decrease with depth, reflecting the relative isolation of deeper waters from recent exchange with the atmosphere. There especially strong penetration of CFC-12 in abyssal, mode and intermediate waters in the southern hemisphere south of 40 ^{o}S, indicating the potential of this region to take up atmospheric gases, including CO_2.

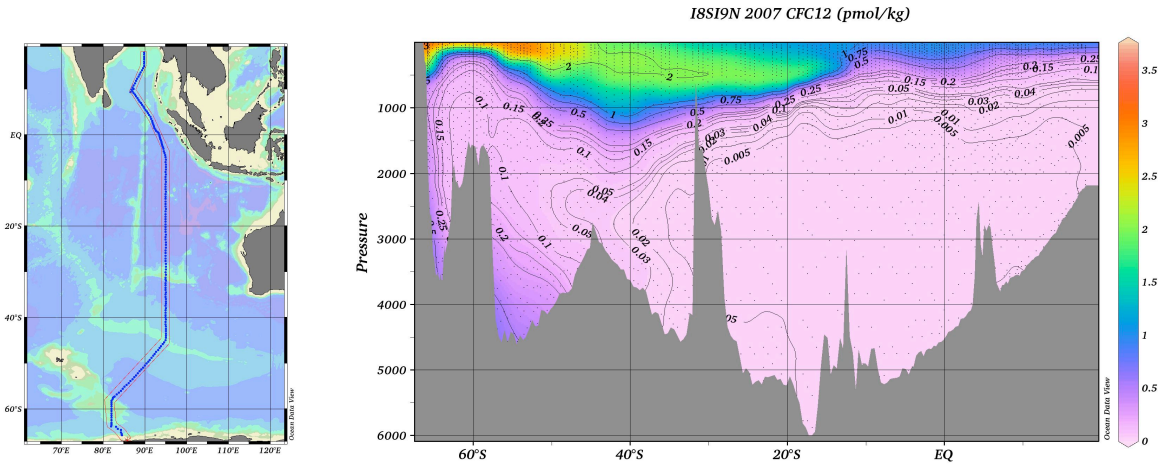

Figure 7. CFC-12 concentrations along I8S/I9N.

Figure 8 shows the concentration of dissolved sulfur hexafluoride (SF_6) along I8SI9N in 2007. The spatial resolution for SF_6 measurements was essentially the same as that for CFC-11 and CFC-12, with at total of ~ 4,100 SF_6 samples analyzed during the expedition.

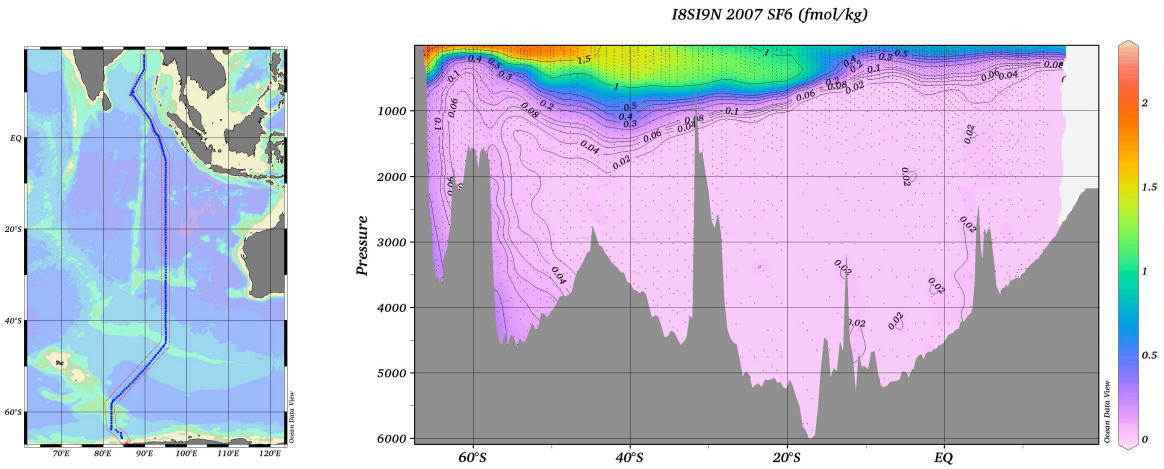

Figure 8. SF6 concentrations along I8S/I9N**.**

Atmospheric concentrations of SF_6 have been increasing rapidly in the atmosphere during the past 2 decades. Along with the CFCs, this compound has the potential to be an extremely useful tracer of ocean circulation and mixing processes, for estimating anthropogenic CO_2 uptake and for multi-tracer dating of water masses (Bullister et al., 2006).

At present, typical concentrations of dissolved SF_6 in surface waters are ~1000 times lower that CFC-12. We hope to develop our analytical techniques to make SF_6 measurement more routine on future repeat hydrography cruises.

3.0 PUBLICATIONS AND REPORTS

FY2007 Publications:

Berelson, W.M., W.M. Balch, R. Najjar, R.A. Feely, C. Sabine, and K. Lee (2007): Relating estimates of $CaCO_3$ production, export, and dissolution in the water column to measurements of $CaCO_3$ rain into sediment traps and dissolution on the sea floor: A revised global carbonate budget. Global Biogeochem. Cy., 21, GB1024, doi: 10.1029/2006GB002803.

Birdsey, R.A., R. Cook, S. Denning, P. Griffith, B.E. Law, J. Masek, A.M. Michalak, S. Ogle, D. Ojima, Y. Pan, C.L. Sabine, E. Sheffner, and E.T. Sundquist (2007): Investigators share improved understanding of the North American Carbon Cycle. Eos Trans. AGU, 88(24), doi: 10.1029/2007EO240004.

Bullister, J.L., and D.P. Wisegarver (2007): The shipboard analysis of trace levels of sulfur hexafluoride, CFC11 and CFC12, in seawater. Deep-Sea Res. [Submitted]

Caldeira, K., D. Archer, J.P. Barry, R.G.J. Bellerby, P.G. Brewer, L. Cao, A.G. Dickson, S.C. Doney, H. Elderfield, V.J. Fabry, R.A. Feely, J.-P. Gattuso, P.M. Haugan, O. Hoegh-Guldberg, A.K. Jain, J.A. Kleypas, C. Langdon, J.C. Orr, A. Ridgwell, C.L. Sabine, B.A. Seibel, Y. Shirayama, C. Turley, A.J. Watson, and R.E. Zeebe (2007): Comment on "Modern-age buildup of CO_2 and its effects on seawater acidity and salinity" by Hugo A. Loáiciga. Geophys. Res. Lett., 34, L18608, doi: 10.1029/2006GL027288.

Chanson, M., F. J. Millero, and R. Wanninkhof (2007), Synthesis and analysis of the carbonate parameters in the Atlantic Ocean based on decadal repeat occupations of the meridional section A16, Global Biogeochemical Cycles, submitted.

Doney, S.C., N. Mahowald, I. Lima, R.A. Feely, F.T. Mackenzie, J.-F. Lamarque, and P.J. Rasch (2007): The impact of anthropogenic atmospheric nitrogen and sulfur deposition on ocean acidification and the inorganic carbon system. Proc. Nat. Acad. Sci., 104(37), 14,580–14,585.

Dugdale, R.C., F.P. Wilkerson, F. Chai, and R.A. Feely (2007): Size-fractionated nitrogen uptake measurements in the equatorial Pacific and confirmation of the low Si–high-nitrate low-chlorophyll condition. Global Biogeochem. Cy., 21, GB2005, doi: 10.1029/2006GB002722.

Feely, and R. Wanninkhof (2007): 3. Global Oceans; f. Global ocean carbon cycle — in *State of*

the Climate in 2006, A. Arguez (ed.).. Bull. Am. Meteorol. Soc., 88 (suppl.)(6), S40–S43.

Johnson, G. C. 2007. Quantifying Antarctic Bottom Water and North Atlantic Deep Water Volumes. *Journal of Geophysical Research*, submitted.

Johnson, G. C., and N. Gruber. 2007. Decadal water mass variations along 20°W in the northeastern Atlantic Ocean. *Progress in Oceanography*, **73**, 277-295, doi: 10.1016/j.pocean.2006.03.022.

Johnson, G. C., S. Mecking, B. M. Sloyan, and S. E. Wijffels. 2007. Recent bottom water warming in the Pacific Ocean. *Journal of Climate*, **20**, 5365-5375.

Kieke, D., M. Rhein, L. Stramma, W.M. Smethie, J.L. Bullister, and D.A. LeBel (2007): Changes in the pool of Labrador Sea Water in the subpolar North Atlantic. Geophys. Res. Lett., 34, 06605, doi: 10.1029/2006GL028959.

LeBel, D.A., W.M. Smethie, Jr., M. Rhein, D. Kieke, R.A. Fine, J.L. Bullister, D.-H. Min, W. Roether, R.F. Weiss, C. Andrie, D. Smyth-Wright, and P. Jones (2006): The distribution of CFC-11 in the north Atlantic during WOCE: Inventories and calculated water mass formation rates. Deep-Sea Res. [Submitted]

Lee, K., L.T. Tong, F.J. Millero, C.L. Sabine, A.G. Dickson, C. Goyet, G.-H. Park, R. Wanninkhof, R.A. Feely, and R.M. Key (2006): Global relationships of total alkalinity with salinity and temperature in surface waters of the world's oceans. Geophys. Res. Lett., 33, L19605, doi: 10.1029/2006GL027207.

Levine, N., M, S. C. Doney, R. Wanninkhof, K. Lindsay, and I. Y. Fung 2007. The impact of ocean carbon system variability on the detection of temporal increases in anthropogenic CO_2, J Geophys. Res., in press.

McGillis (chair and ed.), W., R. Duce, D. Erickson, C. Fairall, D. Farmer, R. Feely, B. Huebert, W. Jenkins, W. Keene, R. Kiene, P. Matrai, K. Melville, W. Miller, R. Najjar, E. Saltzman, P. Schlosser, D. Siegel, W.-J. Cai, D. Ho, S. Doney, K. Johnson, C. McNeil, M.J. Perry, J. Prospero, O. Schofield, P. Shepson, D. Turk, and R. Wanninkhof (2006): The United States Surface Ocean—Lower Atmospheric Study (SOLAS), Science Implementation Strategy. Published in collaboration with the U.S. Ocean Carbon and Biogeochemistry (OCB) program and the International integrated Marine Biogeochemistry Ecosystem Research (IMBER) and SOLAS programs, 123 pp.

Meredith, M. P., A. C. N. Garabato, A. L. Gordon, and G. C. Johnson. 2007. Evolution of the deep and bottom waters of the Scotia Sea, Southern Ocean, during 1995-2005. *Journal of Climate*, submitted.

Peng, T.-H. and R. Wanninkhof, Increase of anthropogenic CO_2 in the Atlantic Ocean in last two decades. (in preparation)

Reay, D.S., C.L. Sabine, P. Smith, and G. Hymus (2007): Spring-time for sinks. Nature, 446(7137), doi: 10.1038/446727a, 727–728.

Reay, D.S., P. Smith, G. Hymus, and C. Sabine (2007): New Directions: The changing role of the terrestrial carbon sink in determining atmospheric CO_2 concentrations. Atmos. Environ.,

41(27), 5813–5815.

Sabine, C.L., and R.A. Feely (2007): The oceanic sink for carbon dioxide. In Greenhouse Gas Sinks, D. Reay, N. Hewitt, J. Grace, and K. Smith (eds.), CABI Publishing, Oxfordshire, UK.

Sabine, C.L., R.A. Feely, and R. Wanninkhof (2007): 3. Global Oceans; f. Global ocean carbon cycle - in State of the Climate in 2006, A. Arguez (ed.).. Bull. Am. Meteorol. Soc., 88 (suppl.)(6), S40–S43.

Sonnerup, R., J. Bullister, and S. Mecking (2007): Circulation rate changes in the eastern subtropical North Pacific based on chlorofluorocarbon ages. Geophys. Res. Lett., 34, L08605, doi: 10.1029/2006GL028813.

Sonnerup, R.E., A.P. McNichol, P.D. Quay, R.H. Gammon, J.L. Bullister, C.L. Sabine, and R.D. Slater (2007): Anthropogenic delta13C changes in the North Pacific Ocean reconstructed using a multiparameter mixing approach (MIX). Tellus, 59B, 303–317.

Steinfeldt, R., M. Rhein, and J.L. Bullister (2007): Inventory changes of anthropogenic carbon in the Atlantic between 1997 and 2003. Nature. [Submitted]

Wanninkhof, R. et al. Decadal changes in inorganic carbon along meridional section A16 in the Atlantic Ocean. (in preparation).

FY2007 Reports

Cronin, M.F., C. Meinig and C.L. Sabine (2006): Global Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO), *Annual Report on the State of the Ocean and the Ocean Observing System for Climat*e, Silver

Feely, R.A., R. Wanninkhof, C. Sabine, G. Johnson, M. Baringer, J. Bullister, C. Mordy and J.-Z. Zhang (2006): Global repeat hydrographic/CO_2/tracer surveys in support of CLIVAR and global carbon cycle objectives: Carbon inventories and fluxes, *Annual Report on the State of the Ocean and the Ocean Observing System for Climat*e, Silver Spring, MD.

Sabine, C.L. and F. Chavez (2006): High-resolution ocean and atmosphere pCO_2 Time-series measurements, *Annual Report on the State of the Ocean and the Ocean Observing System for Climat*e, Silver Spring, MD.

Sabine, C.L., R. Feely, S. Hankin, R. Wanninkhof, T.-H. Peng, A. Kozyr, R. Key, F. Millero and A. Dickson (2006): Global carbon data management and synthesis project, *Annual Report on the State of the Ocean and the Ocean Observing System for Climat*e, Silver Spring, MD.

Relevant Meetings and Presentations in FY07

Sabine:

1) Sustained Indian Ocean Biogeochemistry and Ecological Research (SIBER) Workshop, Goa, India, October 1-8, 2006 (invited talk: Inorganic Carbon Distributions and Air-Sea CO_2 Exchange in the Indian Ocean)
2) NOAA West Coast Synthesis Meeting, Seattle, WA, October 10-11, 2006 (co-organizer and discussion leader)
3) CLIVAR Global Synthesis and Observations Panel (GSOP-2) SSG meeting, La Jolla, CA, Dec. 8-9 (invited talk: Global Carbon and Synthesis needs)
4) AGU Fall Meeting, San Francisco, CA, Dec. 11-15 (invited talk in session: OS04: Variability in Ocean Interior Circulation and Biogeochemistry: Repeat Hydrography and Modeling Studies - Decadal Changes in Pacific Ocean Inorganic Carbon Inventory, coauthor on 5 other abstracts)
5) JAMSTEC 5-year review, Tokyo, Japan, January 17-19, 2007 (invited presentation: Role of IOCCP in international carbon coordination)
6) NACP PI meeting, Colorado Springs, CO, January 22-24, 2007 (invited talk: Carbon Exchanges between the Continental Margins and the Open Ocean; coauthor on 3 posters)
7) NACP SSG Meeting, Colorado Springs, CO, January 24, 2007
8) Joint Canada-US-Mexico NACP meeting, Colorado Springs, CO, January 25-26, 2007 (poster: High Frequency CO2 variability in North American coastal waters; breakout session leader for 2 sessions)
9) NOAA CO_2 Science Team Meeting, Miami, FL, February 4-7, 2007 (meeting organizer and discussion leader)
10) Marshall Islands Workshop, Seattle, WA, March 3, 2007 (participated in discussion of ocean acidification issues with Marshall Islanders).
11) Meeting with King County Executive Board, March 21, 2007 (discussed carbon programs in Puget Sound).
12) IOCCP SSG meeting, Paris, France, April 10, 2007 (chair of meeting)
13) Ocean Surface pCO_2 and Vulnerabilities Workshop, Paris, France, April 11-13, 2007 (invited talks: Moorings: New Results and New Technology Overview, Overview of Proxy Techniques for Data Extrapolation and Interpolation)
14) Anthropogenic Stresses on Ocean Ecosystems Workshop, Seattle, WA, April 23-24, 2007 (breakout discussion leader; invited talk: Existing Technology and Challenges for Monitoring the CO_2 System in Seawater)
15) Seminar to King County Department of Natural Resources and Parks, Seattle, WA, April 25, 2007 (Ocean Storage of Anthropogenic CO_2 and its Impact on Marine Ecosystems)
16) Guest Lecture for Edward S. Sarachik's IPCC fourth assessment report class at UW (taught chapter 7)
17) OCB scientific steering committee meeting, Washington DC, May 3-4, 2007.
18) West coast cruise, R/V Wecoma, Newport OR to San Diego CA May 11-June 14, 2007 (chief scientist).
19) OCB annual summer workshop, Woods Hole, MA, July 23-26, 2007 (discussion leader for day 2 theme on ocean acidification, organizer of day 3 talks and working group on coastal ocean theme).
20) OCB scientific steering committee meeting, Woods Hole, MA, July 27, 2007.
21) NASA ROSES Panel member, Washington DC, August 28-30, 2007.
22) NOAA GCC program PI meeting, Silver Spring MD, September 10-11, 2007 (invited talk on moored CO_2 observations).
23) Southern Ocean GASEX meeting, Silver Spring MD, September 12, 2007 (meeting organizer and convener).
24) Informal discussions about Hawaii mooring program, Honolulu HI, September 14, 2007.

Feely:

1) Byrne, R.H., X. Liu, S. Mecking, and R.A. Feely (2006): Acidification of the North Pacific Ocean: Direct Observations of pH in 1991 and 2006. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract* OS21C-1598.
2) Chanson, M, F.J. Millero, R.A. Feely, C.L. Sabine, and R. Wanninkhof (2006): Decadal Changes in the Carbon Dioxide Parameters in the Atlantic and Pacific Oceans: Anthropogenic, Physical and Biogeochemical Perturbations. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract* OS34B-01.
3) Cosca, C.E., R.A. Feely, B. Tilbrook, P.D. Quay, D. Wisegarver, and L. Juranek (2006): First underway fCO_2 observations from the VOS container ship Columbus Waikato in the tropical and subtropical Pacific. *Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract* OS34J-03.
4) De Carlo, E.H., R.F. Solomon, C. Ostrander, M. Chung, L.E. de Gelleke, M. Akiba, F. Paquay, K.E. Fagan, M.A. McManus, F.T. Mackenzie, C. Sabine, and R.A. Feely (2006): Impact of Short Term Climatic Forcing on Biogeochemical Processes and Gas Exchange between Southern Kaneohe Bay, Hawaii and the Atmosphere. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract* B41E-0227.
5) Dugdale, R., F. Chai, M. Brzezinski, F. Wilkerson, and R.A. Feely (2006): Low Silicate, the cause of the HNLC and High Surface pCO_2 Condition of the Eastern Equatorial Pacific. *Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract* OS42D-01
6) Feely, R.A., C.L. Sabine, R.H. Byrne, and D. Greeley (2006): Direct Evidence for Ocean Acidification of the North Pacific Ocean. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstrac*t OS12B-04.
7) Feely, R.A., T. Takahashi, R. Wanninkhof, C.E. Cosca, M.J. McPhaden, S.C. Sutherland, M.-E. Carr, and F. Chai (2006): Interannual and Decadal Variability of the Air-Sea CO_2 Fluxes in the Equatorial Pacific Ocean. *Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl, Abstract* OS42D-03.
8) Lueger, H., R. Wanninkhof, R. Castle, R.A. Feely, C. Neill, A. Olsen, T. Johannessen, D. Pierrot, F. Millero, T. Steinhoff, D.R. Wallace, and A. Koertzinger (2006): Common Data Reduction Practices for Underway fCO_2 Measurements by Ships of Opportunity. *EOS Trans. AGU, 87(36), Ocean Sci. Meet Suppl., Abstract* OS34J-04.
9) Mecking, S., C. Langdon, C.A. Deutsch, R.A Feely, C.L. Sabine, J.H. Swift, D. Min, and P.E. Robbins (2006): Climate Variability in the North Pacific Thermocline Diagnosed from Oxygen Measurements: An Update Based on the U.S. CLIVAR/CO_2 Repeat Hydrography Cruises. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract* OS33D-06.
10) Parker, A.E., A. Marchi, V.E. Hogue, K. Lew, A. Lorenzi, D. Greeley, R A. Feely, F. Wilkerson, and R.C. Dugdale (2006): Nutrient Utilization and Phytoplankton Community Response During Enclosure Experiments Conducted in the Eastern Equatorial Pacific: Testing Fe vs. Si Limitation. *Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract* OS35F-08.
11) Rodgers, K.B., O. Aumont, J.L. Sarmiento, A. Jacobson, C. Crevoisier, R.A. Feely, C. Sabine (2006): A Modeling Study of Seasonal to Decadal Variabiltiy in the Uptake of Antrhopogenic CO_2 in the North Pacific. *Eos Trans. AGU, 87(36), Ocean Sci. Meet. Suppl., Abstract* OS52C-06.

12) Sabine, C.L., R.A. Feely, F.J. Millero, A. Dickson, S. Mecking, R. Wanninkhof, and D. Greeley (2006): Decadal Changes in Pacific Ocean Inorganic Carbon Inventory. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract* OS33D-05.

13) Solomon, R.F., C.E. Ostrander, M. Chung, F. Paquay, L. de Gelleke, M. Akiba, K.E. Fagan, E.H. De Carlo, F.T. Mackenzie, M.A. McManus, C.L. Sabine, and R.A. Feely (2006): The Effects of Storm Events on Carbon Dioxide Exchange in Southern Kaneohe Bay, Hawaii. *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract* OS21A-1566.

14) Talley, L., N. Bindoff, C. LeQuere, R.A. Feely, G.C. Johnson, C. Sabine, S. Mecking, J. Swift, N. Gruber, C. Deutsch, and I. Yashayaev (2006): Overview of Decadal Variations in Salinity, Oxygen and Nutrients Based on Recent Repeat Hydrographic Sections. *Eos Trans. AGU, 87(52), Fall Meet.* Suppl*., Abstract* OS33D-01.
15) NOAA West Coast Synthesis Meeting, Seattle, WA, October 10-11, 2006 (co-organizer)
16) NOAA CO_2 Science Team Meeting, Miami, FL, February 4-7, 2007 (co-organizer)
17) Marshall Islands Workshop, Seattle, WA, March 3, 2007 (discussion leader on ocean acidification issues with Marshall Islanders).
18) Meeting with King County Executive Board, March 21, 2007 (discussed carbon programs in Puget Sound).
19) IOCCP SSG meeting, Paris, France, April 10, 2007 (co-organizer) Ocean Surface pCO_2 and Vulnerabilities Workshop, Paris, France, April 11-13,
20) Anthropogenic Stresses on Ocean Ecosystems Workshop, Seattle, WA, April 23-24, 2007 Co-organizer and Keynote speaker)
21) West coast cruise, R/V Wecoma, Newport OR to San Diego CA May 11-June 14, 2007 (chief scientist).
22) OCB annual summer workshop, Woods Hole, MA, July 23-26, 2007 OCB scientific steering committee meeting, Woods Hole, MA, July 27, 2007.
23) NOAA GCC program PI meeting, Silver Spring MD, September 10-11, 2007 (invited talk on ocean acidification).
24) Southern Ocean GASEX meeting, Silver Spring MD, September 12, 2007 (meeting organizer and presenter).
25) European Science Foundation, Barcelona Spain. Invited talk on ocean acidification. September, 26, 2007.

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